thought an Attempt to render it more so, would not be altogether useless, or yet unworthy the Notice of the Curious.

VIII. *A new Method of improving and perfecting* Catadioptrical Telescopes, *by forming the* Speculums *of* Glass *instead of* Metal. *By* Caleb Smith.

THE Telescope is deservedly reckoned one of the most excellent of all the Inventions of the Moderns; such noble and useful Discoveries have been made by means of this admirable Instrument, and are still to be expected from its further Improvement, that many of the most eminent Mathematicians have imployed their utmost Skill and Industry to bring it to Perfection.

The Imperfections of Telescopes are attributed to two Causes; to wit, The Unfitness of the Spherical Figure to which the Glasses are usually ground, and the different Refrangibility of the Rays of Light.

The first of these Defects only, was known to the Writers of Dioptrics, before Sir *Isaac Newton*; for which Reason (as he informs us himself, *Opt. Lect.* 1, 2.) they "imagined, that Optical Instruments "might be brought to any Degree of Perfection, "provided they were able to communicate to the "Glasses, in grinding, what Geometrical Figure they "pleased; to which Purpose various Mechanical "Contrivances were thought of, whereby Glasses "might be ground into Hyperbolical, or even Para-

"bolical,

" bolical, Figures; yet nobody ſucceeded in the " exact Deſcription of ſuch Figures; and had their " Succeſs been anſwerable to their Wiſhes, yet their " Labour would have been loſt (continues this " incomparable Mathematician); for the Perfection " of Teleſcopes is limited, not ſo much for want of " Glaſſes truly figured, according to the Preſcriptions " of Optic Authors, (which all Men have hitherto " imagined) as becauſe that Light itſelf is an hetero- " geneous Mixture of differently refrangible Rays; " ſo that were a Glaſs ſo exactly figured as to collect " any one ſort of Rays into one Point, it could not " collect thoſe alſo into the ſame Point, which " having the ſame Incidence upon the ſame Medium, " are apt to ſuffer a different Refraction" (*Phil. Tranſ.* N°. 80.). And again,—— " Diverſa diver- " ſorum Radiorum Refrangibilitas Impedimento eſt, " quo minus Optica, per Figuras, vel ſphæricas, vel " alias, perfici poſſint; niſi corrigi poſſint Errores " illinc oriundi, Labor omnis in cæteris corrigendis " imperite collocabitur" (*Principia, &c. Scholium ad finem Libri Primi).*

Now, for this principal and laſt-mentioned Defect, no one, that we know of, has propoſed any Remedy; apprehending, perhaps, the Difficulty of attaining ſuch to be inſuperable; inaſmuch as the great Author of this Diſcovery, himſelf, had not ſhewed us any Method whereby to correct thoſe Errors which ariſe from this Inequality of Refraction; but rather diſcouraged any ſuch Attempts, by declaring, " that " on this Account he laid aſide his Glaſs-works," (*Phil. Tranſ.* N°. 80.) " and looked upon the " Improvement of Teleſcopes, of given Lengths, " by

"by Refraction, as desperate" (*Optics*, 2d Edit. *p.* 91.).

However, as it has been proved by incontestable Experiments, that this Dissipation of the Rays of Light, from whatever Cause it proceeds, in passing out of one Medium into another, is not accidental and irregular; but that every sort of homogeneal Rays, whether more or less refrangible, considered apart, are refracted according to some constant uniform and certain Law; and as the Removal of so great an Impediment as this of unequal Refraction in the Rays of Light, is of great Importance to the Science of Dioptrics, and absolutely necessary to its further Advancement; we have thought it worthy of a careful Examination, whether, in some Cases at least, it might not be possible for contrary Refractions so to correct each other's Inequalities, as to make their Difference regular; and if this could be conveniently effected, Sir *Isaac Newton* has acknowledged, "there would be no farther Difficulty" (*Phil. Transf.* No. 88).

Now, upon a due Consideration of this Subject, we have found it possible, by proper Methods and Expedients, to rectify those Errors which proceed from the different Degrees of Refrangibility in different Rays, passing from one Medium into another; admitting only this well-known and established Principle, upon which we ground our Reasoning, *viz.* "That the Sines of Refraction of Rays differently "refrangible, are one to another in a given Pro-"portion, when their Sines of Incidence are equal" (*Optics*, 2d Edit. p. 66.). And our present Design is, to shew what Advantage this will yield towards im-

improving and perfecting Catadioptrical Telescopes, by making the Speculums of Glass, instead of Metal, in the following Manner:

Fig. 1.

Let the Figure *ABCDEF* represent the Section of a concavo-convex Speculum, whose two Surfaces are Segments of unequal Spheres; call the Radius of the Sphere, to which the concave Side is ground, *a*; and the Radius of the convex Surface, which must be quicksilver'd over, *e*; let *BR* be the Axis of the Speculum, or a Line perpendicular to both the Surfaces; and therein let *P* be the principal Focus, or Point where parallel Rays of the most refrangible Kind are collected, by this Speculum; and *Q* the Focus, or Point of Concourse, of such Rays as are least refrangible; to wit, after they have suffer'd two Refractions, at entering into, and passing out of, the concave Surface *DEF*, and also one Reflection from the convex Surface *ABC*: If the Radius of Concavity be greater than the Radius of Convexity, as we will in the first Place suppose, then *P* will fall nearer the Vertex of the Speculum than the Point *Q*; and the Interval *QP* will be the greatest Aberration, or Error, occasioned by the Separation, or unequal Refraction, of the greatest and least refrangible Rays, after their Emergence from

from the concave Surface *FED*. Call the common Sine of Incidence, n; the Sine of Refraction of the least refrangible Rays out of a dense Medium into a rarer, m; and, of the most refrangible, μ; then, according to the known and received Laws of Refraction and Reflection, the Focal Distance of the most refrangible Rays, from the Vertex of the Speculum, (neglecting its Thickness, as of little or no Moment in the present Case) will be found $= \frac{nae}{(a-e)2\mu+2ne} = PB$. And the Quantity of the greatest Aberration, occasioned by the different Refrangibility of the most and least refrangible Rays, PQ, will be to the focal Distance just mentioned, PB, as $(a-e) \times (\mu-m)$ to $(a-e)m+en$; which Quantity, or Error, thus obtained, (to abbreviate the Calculation) call ε; and now let it be required to form a Lens, if possible, which, placed at some given Point in the Axis between the Focus of the most refrangible Rays P, and the Vertex of the Speculum (as H), shall refract not only the Rays of the most refrangible Kind tending to the Point P, but also the Rays of the least refrangible Kind tending to Q, in such a Manner, that both Sorts shall concur, after such Refraction, in some other Point of the Axis R; let HP the given Distance of the Point in the Axis H, from the Focal Point P, be called d; and then if the Point H has been assumed, so that the said given Quantity, or Distance, d, is greater than $\frac{(\mu-n)\varepsilon}{\mu-m}$, but less than $\frac{m\varepsilon}{\mu-m}$, I say the refracting Superficies *GHI*, that shall perform what was required, will be part of a concave Sphere, whose

whose Radius is $= \frac{(dd + d\varepsilon) \times (\mu - m)}{m\varepsilon - (\mu - m) d}$; and *HR*, the Distance of the given Point *H*, from *R*, the Point to which all the Rays will tend, after Refraction at the said concave Surface, (whose Radius being found, as above, we call υ) will be $= \frac{\mu d \upsilon}{(d + \upsilon) n - \mu d}$. Lastly, upon the Point *R* thus obtained, as a Centre, with an Interval a little less than *HR*, describe the Circumference *KLM*, and the Figure *GHIMLK* will denote the Section of a double concave Lens, which, placed at the given Point in the Axis *H*, (taken nevertheless within the Limits above-mentioned) will collect all Sorts of Rays proceeding from the Speculum, into one and the same Focus, or Point of the Axis, *R*, as was required; for the Surface *GHI*, which first receives those Rays, will refract the most refrangible Sort converging to the Point *P*, and also the least refrangible converging towards *Q*, so that both Sorts, after such Refraction, will concur in the Point *R*; but the Rays tending to *R*, 'tis manifest, will suffer no Refraction at their Emergence from the Superficies *KLM*, because *R* is the Centre thereof, by Construction; which Point, *R*, where a perfect Image of an Object infinitely distant will be formed, we call the Focus of the Telescope, to distinguish it from the Point, *P*, which we have before called the Focus of the Speculum.

In this manner a Lens, (or instead thereof a triangular Prism with two of its Sides ground concave, and the third plain, if that be found as practicable) may be formed and situated, so as to correct the Errors of the Speculum arising from the different

Refrangibility of the Rays of Light. But, in order to render this kind of Telescopes absolutely perfect in their Construction, the Errors also that result from the spherical Figure, must be rectified; and with regard to this, we assert, that it is possible to assume a Point in the Axis, between the Focus of the Speculum and its Vertex, (as we have taken the Point *H*, in the following Example, see Fig. 2. p. 337.) at which, if a refracting Superficies, or Lens, be constituted, according to the Method already delivered, it will not only correct the Errors occasioned by the unequal Refraction of the Rays of Light, but also rectify such as proceed from the spherical Figure of this Speculum, to a much greater Degree of Exactness than is requisite for any Physical Purpose (meaning always the Errors of those Rays which respect the Axis). Now to find or determine this Point, affords a Problem not easy to be solved; and we recommend it, as worthy of the Consideration of Geometricians.

Seeing therefore it is possible, and we believe also practicable, to remedy the Imperfections of this kind of Speculums, (from whatsoever Cause they arise) by the Method we have here proposed; it seems to follow, that Catadioptrical Telescopes may be carried, by this means, to as great a Degree of Perfection, as they are capable of receiving; provided spherical Figures can be truly communicated, with an exquisite Polish, to Glasses of a large Aperture, and a Foil of Quicksilver made also to retain that Figure accurately, and without any Inequality; for the Object-glass or Speculum being rendered perfect, so as that all sorts of Rays, proceeding from one lucid Point in its Axis,

Axis, ſhall be collected by means of the Lens exactly in another Point, its Aperture may then be extended to its furtheſt Limits; and that is, till the whole Pupil of the Eye (or the whole Portion of the Eye-glaſs to be uſed, when that becomes neceſſarily leſs than the Pupil) be filled with Rays proceeding from the Speculum, and flowing from one Point of the Object, but no farther; becauſe this is a Limitation made by Nature in the Structure of the Eye itſelf: And in Teleſcopes whoſe Conſtruction is ſuch as we have now deſcribed, the largeſt Aperture of the Speculum that can ever be of Uſe, will be to the Diameter of the Pupil of the Eye, very nearly, in a *Ratio* compounded of the *Ratio's* of the Focal Length of the Speculum to the Diſtance of that Focus from the Lens, and of the Diſtance of the Lens from the Focus of the Teleſcope, to Unity: That is, of *BP* to *PH*, and of *RH* to 1; which Proportion holds, whatever be the Charge or the Power of Magnifying.

But if Inquiry be made as to the Charge moſt proper and convenient, that will be determined beſt by Experience, in theſe, as well as in all other ſorts of Teleſcopes: However, on Suppoſition that one of a given Length has its Aperture and Charge rightly ordered and proportioned, the Rule for preſerving the ſame Degree of Brightneſs and Diſtinctneſs, in all others of a like Conſtruction, will be, to make the Apertures, and magnifying Powers, directly as the Focal Lengths of the Speculums; which ſhews the vaſt Advantage and Perfection of theſe Teleſcopes, above the common reflecting ones; where, according to Sir *Iſaac Newton*'s Rule, the Apertures, and

Powers of Magnifying, muſt be as the Biquadrate Roots of the Cubes of their Lengths (See his *Optics*, 2d Edition, p. 97.).

It is likewiſe a conſiderable Advantage in this Conſtruction, that the Reflection from the concave Side of the Speculum will do no ſenſible Prejudice; becauſe the Image of any Object made thereby, is removed to ſo vaſt a Diſtance from the principal Image, formed by the convex Surface, as to create no manner of Confuſion or Diſturbance in the Viſion; which neceſſarily happens, in ſome Degree, from the Vicinity of thoſe Images, when the Glaſs is ground concave on one Side, and as much convex on the other; according to the Method propounded by Sir *Iſaac Néwton*, in his moſt excellent Book of *Optics*.

It may be imagined, perhaps, at firſt View, that (if our Reaſoning is juſt) the Errors of refracting Teleſcopes, occaſioned by the different Refrangibility of Light, may be corrected by a like Artifice: But the Aberration of the Rays from the principal Focus is there ſo great, and bears ſo conſiderable a Proportion to the Focal Length of the Teleſcope, that the Error cannot be rectified by the Interpoſition of any Lens, until the Rays are, by a contrary Refraction, collected again at an infinite Diſtance, which renders this Expedient quite uſeleſs; however, there is no need to deſpair of accompliſhing even this, by other Methods: And, by the way, we may obſerve, if it were worth while to ſeek a Remedy for the Errors occaſioned by the ſpherical Figure of the Object-glaſs only, in Dioptrical Teleſcopes; that might be obtained by the proper Application of a
ſuitable

ſuitable Lens, between the Focus and the Vertex of the Object-glaſs; which is much more eaſy and practicable, than the grinding of Glaſſes to Hyperbolical or Elliptical Figures.

For a further Illuſtration of what is gone before, it may be proper to exhibit the ſeveral Parts and Proportions of a Teleſcope in Numbers computed according to the Theorems already delivered; and in Practice we judge it will be moſt convenient, that the *Radii* of the Spheres to which the concave and convex Sides of the Speculum are ground, be nearly in the Ratio of 6 to 5; as in the following Example; where (ſee Fig. 2. p. 337.)

ABCDEF, repreſents the great Speculum of Glaſs, ground concave on one Side, and convex on the other; quickſilver'd over the convex Side, and of an equal Thickneſs all round its Circumference.

The *Radius* of Concavity $= a = 48$ Inches.

The *Radius* of Convexity $= e = 40$ Inches.

Then putting n, the Sine of Incidence $= 100$; m, the Sign of Refraction of the leaſt refrangible Rays, out of Glaſs into Air, $= 154$; and μ, the Sine of Refraction of the moſt refrangible Rays, $= 156$; as Sir *Iſaac Newton* found them by Experiments; we ſhall have,

PB, the Focal Length of the Speculum with regard to the moſt refrangible Rays $= 18.2926 +$, which will be ſomewhat increaſed by the Thickneſs of the Glaſs, when that is conſiderable.

PQ, the greateſt Aberration of the Rays, occaſioned by their different Degrees of Refrangibility, $= .05594 +$, which Quantity, in Practice, ſhould be

be a very little augmented, rather than otherwiſe; wherefore we put it here $= .056 = \varepsilon$.

The *Radius* of the concave Surface of the Lens, turn'd towards the Speculum, *viz.* of *GHI*, $= \upsilon = 2.8$ Inches.

The *Radius* of the concave Surface of the Lens, turn'd from the Speculum, *viz.* of *KLM*, $= 6.7$ Inches.

The Thickneſs of the Lens at the Vertex $LH = \frac{1}{10}$ of an Inch.

The Aperture of the Lens muſt be about $\frac{1}{6}$ of the Aperture of the Speculum.

HP, the Diſtance of the Focal Point *P* from the Point *H*, where the aboveſaid Lens is to be placed, ſo as to correct the Errors ariſing from the different Refrangibility of the Rays, and alſo the Errors of the ſpherical Figure, $= 2.\frac{24}{73}$ Inches.

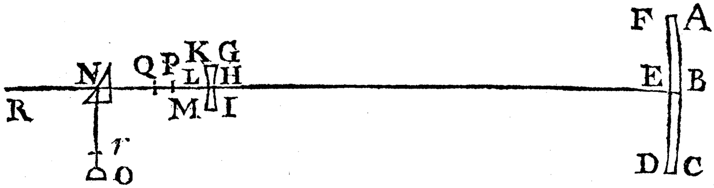
HR, the Diſtance of *H* the Vertex of the Lens from *R* the Focus of the Teleſcope, $= 6.8$ Inches.

And if we ſuppoſe the Diameter of the Pupil of the Eye to be ^{1} of an Inch, (though it has not one certain Meaſure) then the Diameter of the greateſt Aperture of the Speculum, that can ever be of Uſe, will be $6\frac{2}{3}$ Inches, nearly.

The ſmall plano-convex Eye-glaſs *O* muſt always have one common Focus with the Teleſcope, to wit, the Point *R* tranſlated to *r*, by Reflection from the Baſe of the Priſm *N*; for which Reaſon it muſt retain, at all times, an equal and invariable Diſtance from the Lens *GHIKLM*; which Diſtance will be the Focal Length of the ſaid Eye-Glaſs more *HR* $(= HN + Nr)$ the Diſtance of the Lens from the Focus of the Teleſcope *R*.

The

Fig. 2.



The Form and Poſition of the Priſm *N*, and the Contrivance of the other Parts neceſſary, will be much the ſame as in the *Newtonian* Teleſcope.

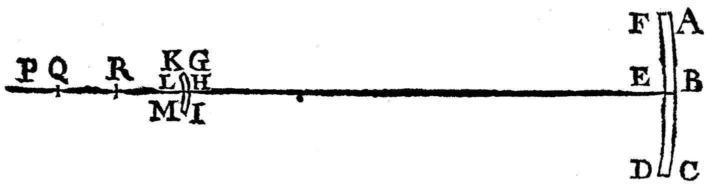
If the Focal Length of the Eye-glaſs be $\frac{1}{4}$ of an Inch, the Teleſcope will magnify about 200 times.

This Teleſcope may be contrived in the *Gregorian* way, by uſing, inſtead of a Lens and Priſm, a ſmall Speculum ſpherically concave on one Side, and convex on the other; but we think it not worth while to attempt this Conſtruction, as an Inveſtigation of the Proportion between the two Surfaces neceſſary, in this ſmall Speculum, to unite the Rays proceeding from the great one, into one Point, would be intricate, and the Practice alſo very difficult; by reaſon that a little Inaccuracy will, in this Caſe, occaſion Errors much more conſiderable than a like Imperfection in the refracting Lens.

We have hitherto ſuppoſed the *Radius* of the Concavity greater than that of the Convexity; as being moſt convenient and uſeful, on ſeveral Accounts, in forming this kind of Teleſcopes; however, it may be proper to remark, that the ſame Method may be uſed for correcting the Errors of the Speculum, when the *Radius* of its Concavity is leſs than that of the Convexity; only the refracting Superficies of the Lens, placed between its Vertex and Focus, will be

be convex, and not concave, as in the former Case. And there is another thing worthy of Remark, that the Focus, or Point (*P*), where the most refrangible Rays are collected, will fall farther from the Vertex of this Speculum, than the Focus of the least refrangible (*Q*); a Circumstance which never happens by Refraction alone, in Glasses of any Figure whatsoever, or howsoever they be disposed.

Fig. 3.



Now all things being put as before, and making (Fig. 3.) $HQ = d$, I say the convex Superficies *GHI* of a Lens placed at *H*, that shall correct the Errors arising from the different Refrangibility of Rays, in this kind of Speculum, will be part of a Sphere, whose *Radius* is $= \frac{(\mu - m) \times (dd + d\varepsilon)}{(\mu - m)d + n\varepsilon} = v$. And *HR*, the Distance of the Point *R*, where the Rays of all sorts will unite, after this Refraction, from *H* the given Point in the Axis, will be $= \frac{\mu d v}{(\mu - n)d + nv}$; which Point *R* being taken as a Centre, describe thereon the Arch *KLM*, and the Figure *GHIMLK* will represent the Section of a Meniscus-glass, or Lens, which, placed at the Point *H*, assumed between the Vertex and Focus of the Speculum, will collect all sorts of Rays proceeding therefrom into one and the same Point, or Focus, *R*. We might also shew, how

how this Error may be rectified by one or more Glaſſes, placed in the Axis, at a Diſtance farther from the Vertex than the Focal Point *P*; but the former Speculum is ſo much preferable to this, for the conſtructing of Teleſcopes, that we think it not worth while to proſecute this Matter farther. To conclude this Eſſay;

Whoever ſhall think fit to put the Method here propoſed in Execution, we dare venture (from a Trial that has been made) to aſſure him of Succeſs; provided the ſame Diligence, Care, and Accuracy, be applied, in chooſing, figuring, poliſhing and foiling, the Glaſs, that has of late been employed for the forming Speculums of Metal; and let none be diſcouraged, though the firſt and ſecond Attempt ſhould fail; for that muſt be expected, if the ordinary way of grinding and poliſhing be uſed: Greater Exactneſs is here required, than is uſually thought ſufficient for the Object-glaſſes of refracting Teleſcopes: Let it be alſo conſidered how many Eſſays, for a long Term of Years, were made by Mr. *Gregory*, Sir *Iſaac Newton*, and others, to reduce their Conſtructions of the reflecting Teleſcope into Practice, without anſwering, in any tolerable Degree, what their Theories promiſed: The Workmen they employed were chiefly Optical Inſtrument-makers, and had it been left to ſuch Perſons only to perform by themſelves, we have reaſon to think, that it would have been pronounced impracticable to this Day, to make a reflecting Teleſcope that ſhould equal or excel refracting ones of Ten times its Length; though we now ſee, that moſt of theſe Artificers are

capable of making them to ſuch a Degree of Perfection as was formerly deſpaired of.

April 5. 1739.

IX. *Extract of a Letter from the Hon^ble^* Henry Temple, *Eſq; to his Father the Right Hon^ble^ the Lord Viſcount* Palmerſton, *concerning an* Earthquake *at* Naples; *communicated to the* Royal Society *by* Claudius Amyand, *Eſq;* F. R. S. *and Sergeant Surgeon to His* MAJESTY.

Naples, Dec. 12. *N. S.* 1732.

—THEY tell me, the laſt Earthquake here has made a great Crack in the Side of Mount *Veſuvius*, above 30 Yards long. I am not ſure if this be true or not, though I think it very poſſible; but I made another Obſervation upon it, which I think much more extraordinary; which is, that the ſecond Shock, which was a very ſlight one, had a great Effect upon the Nerves: I and all the Company where I was, as ſoon as the Shock was over, were ſeized with a Shaking, juſt as if we all had the Palſy, our Teeth chattering in our Heads to ſuch a degree, that we could hardly ſpeak; and I find, that half the Town felt the ſame Effect from it. It would be natural to imagine, that this Shaking was cauſed by the Fright, but it is eaſy to prove the contrary; becauſe, in the firſt place, the firſt Shock, which was much more terrifying, had not that Effect: Secondly,